Intense fires promote uncommon post-fire ephemerals in Currawang *Acacia doratoxylon* dry scrubs of Little River Gorge, East Gippsland

Suzanne M Prober[1], Kevin R Thiele[2] and M Bramwell[3]

[1]CSIRO Sustainable Ecosystems, Private Bag 5, Wembley, Western Australia 6913
[2]Department of Environment and Conservation, LMB 104, Bentley Delivery Centre, Western Australia 6983
[3]Department of Sustainability and Environment, 574 Main Street, Bairnsdale, Victoria 3875

Abstract

Acacia scrubs are an unusual vegetation community in the Upper Snowy River region of Victoria and New South Wales, occurring as sharply-delineated patches amongst eucalypt forest on steep, rocky, north to west facing slopes. They can be dominated by a range of *Acacia* species, but understoreys of *Acacia* scrubs are generally reported as sparse and species poor, and little is known of their ecology. Extensive wildfires in 2003 provided an opportunity to compare the effects of mild and intense fires on plant species composition and vigour in *Acacia* scrub communities of the Little River Gorge in eastern Victoria. *Acacia* scrubs at this site were dominated by *Acacia doratoxylon,* not previously described as a dominant in *Acacia* scrubs in Victoria. Consistent with earlier observations, understoreys in unburnt scrubs were usually sparse. Light burns led to minimal change in understorey abundance, and sporadic establishment of a range of species that were uncommon in the understorey of unburnt sites. By contrast, burns that were intense enough to kill the *Acacia* overstorey stimulated dense establishment and profuse growth of species that were rare or absent in the understorey of unburnt plots, leading to a dramatic increase in native shrub richness and understorey abundance. Processes leading to these understorey changes are likely to involve both effects of fire on seed dormancy, and release from intense competition for resources after overstorey death. Infrequent, intense fires have previously been recognised as important for stimulating recruitment of overstorey species and thus the perpetuation of *Acacia* scrubs in far south-eastern Australia. This study indicated that a diverse range of understorey species are also dependent on intense fires in these communities, where they appear to behave as post-fire ephemerals. Further, many of these species are listed as rare or vulnerable in Victoria, and thus the appropriate fire management of *Acacia* scrubs is of significant conservation interest. *(The Victorian Naturalist* **124** (6), 2007, 320-331)

Introduction

Dry sclerophyll forests or 'scrubs' dominated by *Acacia* species form an anomalous vegetation community in the Snowy River region of eastern Victoria. They occur as sharply-delineated patches on steep, rocky north and west facing slopes within a matrix of eucalypt-dominated vegetation. Together with related scrubs of south-eastern NSW, these scrubs form the only class of vegetation east of the Great Dividing Range in which *Acacia* is the dominant tree (Keith 2004). They are not closely related to any other classes of vegetation in the region, although they share some floristic similarities with rocky outcrops in the adjacent sclerophyll forests (Keith 2004). In eastern Victoria, they are known as rocky outcrop scrubs (EVC 27, Woodgate *et al.* 1994; previously rocky-outcrop open scrubland community of Forbes *et al.* 1982).

Various *Acacia* species (*A. binervia, A. blayana, A. doratoxylon, A. falciformis, A. kettlewelliae* and *A. silvestris*[1]) have been recorded as dominants in different scrub patches (Costin 1954, Clayton-Greene and Wimbush 1988, Keith and Bedward 1999). In the Snowy River region, Clayton-Greene and Wimbush (1988) found *Acacia silvestris* was dominant in most stands. The understorey of *Acacia* scrubs is usually reported as sparse, with scattered shrubs and minimal ground cover, but a dense shrub layer, particularly of *Philotheca trachyphylla* (sometimes without the *Acacia* overstorey) can also occur (Forbes *et al.* 1982, Clayton-Greene and Wimbush 1988, Keith 2004). Keith (2004) describes the community as typically species-poor, with only about a dozen species per 0.1 hectare.

Little is known about the ecology of dry *Acacia* scrubs (Clayton-Greene and Wimbush 1988). The even-aged nature of mature *Acacia* stands indicates that intense fires are important for their regeneration.

In these conditions, mature trees are killed and germination and growth of seedlings is stimulated (Clayton-Greene and Wimbush 1988). However, there is little documentation of effects of fire on other species in these communities, and patterns in species composition relating to other environmental factors are poorly understood.

Extensive wildfires in 2003 provided an opportunity to study the effects of fire on dry *Acacia* scrub communities on Lower Devonian volcanics of the Little River Gorge in East Gippsland, Victoria. We undertook stratified floristic surveys to assess short-term impacts of mild and intense fire on understorey composition and vigour, and to establish benchmarks for monitoring vegetation response to fires over a longer time frame. Surveys were also relevant to management of habitat of the Brush-tailed Rock Wallaby *Petrogale penicillata* (JE Gray 1825), as the Little River Gorge area provides the last remaining refuge for this species in Victoria.

The Study Area

The Little River, upstream of its junction with the Snowy River in East Gippsland, forms Victoria's deepest gorge. The area is highly dissected, with steep slopes and deep valleys ranging in elevation from 200 to 1000 m A.S.L., and occupies a rain shadow with an average of around 600 mm rainfall per annum. Soils are derived from Lower Devonian volcanics (rhyodacites), and contrast with the coarse grained granodiorites and Upper Ordovician sediments (siltstones, schists, slates, shales and claystones) occurring immediately to the north and east (Clayton-Green and Wimbush 1988).

Typical vegetation of the local region is grassy woodland dominated by White Box *Eucalyptus albens*, grading to other eucalypt forests and woodlands at higher altitudes and on poorer soils. Dry *Acacia* scrubs occur as scattered patches associated with steep rocky valleys and slopes amongst these vegetation types, both on rhyodacites and sediments, but rarely on granodiorites (Clayton-Greene and Wimbush 1988).

Large areas of the Little River valley were burnt in the extensive Bogong Complex wildfires during January 2003. Fire intensity varied depending on aspect, fuel loads and weather conditions, leading to a mosaic of unburnt, lightly burnt and intensely burnt areas across the gorge.

Methods

Sampling

Floristic sampling focused on two areas of known *Petrogale penicillata* habitat on the northern slopes of Little River (37° 06' S, 148° 20' E) and Farm Creek (a tributary of Little River, 37° 07' S, 148° 20' E). Vegetation was dominated by tall *Acacia* scrub on dry slopes and spurs, with *E. albens* woodlands on locally cooler (eastern) aspects, and shrubland dominated by *P. trachyphylla* on exposed rocky outcrops. Some intergrading occurred among these communities, especially at Farm Creek.

Sampling was undertaken in November 2004 to January 2005, and was confined to vegetation with a prominent *Acacia* overstorey. Quadrats were 10 x 10 m, and permanently marked to allow long-term monitoring. Although the study was undertaken almost two years after the Bogong Complex fires, a range of fire intensities was easily distinguishable:

- Sites with deep, non-charred, ground-layer litter and occasional live shrubs with sparse to abundant twig-lichens (*Usnea* sp.), were classed as *unburnt*.
- Sites with visible charcoal and partially burnt twigs, fire-scars on trees and larger shrubs, no twig-lichens, and <20% kill of the *Acacia* canopy were classed as *lightly burnt*.
- Sites with >80% kill of the overstorey *Acacia* trees were classed as *intensely burnt*.

At each site we aimed to sample four replicates each of unburnt, lightly burnt and intensely burnt *Acacia* scrub. However, no unburnt sites were found at Little River, so the final sampling design comprised four unburnt plots (Farm Creek only), eight lightly burnt plots and eight intensely burnt plots (both sites).

Plots were placed so as to sample the range of topographic classes present at each site (NE to NW slopes, drainage lines and rocky spurs). Within each topographic class, we sought to place plots of each fire intensity class within close proximity, leading to paired (lightly-burnt and intensely-burnt) plots at Little River, and sets of three (unburnt, lightly-burnt and intensely-burnt plots) at Farm Creek. Plots were randomly placed within these constraints.

Floristic monitoring

Percentage foliage projective cover was visually estimated for all higher plant and fern species and for bare ground, litter and rock cover. Species that were present at <1% visual cover were allocated a nominal cover of 0.5%. This may have led to over-estimates of total cover, as species were often present at very low cover. A range of other variables (richness and cumulative cover for native and shrub cover including and excluding *P. trachyphylla,* forb cover, grass cover and exotic cover) were calculated from primary data.

Data analysis

Richness and cover estimates were analysed in GenStat (2003), using general linear regression to perform analysis of variance of the unbalanced 8 block (pair or triplet) x 3 fire intensity design. It was assumed that effects of fire intensity were consistent across sites (i.e. that there was no site x fire intensity interaction), and that fire intensity and pre-fire vegetation composition were not significantly confounded. For each variable showing a significant overall effect, treatment means adjusted for block effects were calculated and compared using post-hoc tests (Fisher's Protected Least Significant Differences, Steel and Torrie 1981).

Ordination was used to explore patterns in understorey composition. Two ordinations were performed and compared, one using presence-absence floristic data and one using quantitative floristic data. For each analysis, floristic data (excluding tree species) were used to produce a distance matrix using the Bray-Curtis coefficient of dissimilarity (Faith *et al.* 1987). Non-metric multidimensional scaling (nMDS) analyses were performed on the distance matrices using the software package DECODA (Minchin 1989), and results were transferred to PC-ORD (McCune and Mefford 1999) for plotting and visual analysis. Analyses were performed in one to five dimensions using 10 random starts and global nMDS. Considerable stress reduction from the two to the three dimensional solutions, compared with minimal improvement in higher dimensions, led to selection of the three-dimensional solution for further exploration. Stress values of the selected solutions were 0.11 for the presence-absence and 0.10 for the quantitative analysis.

Correlations of environmental attributes with the distribution of sites on the final ordinations were examined by plotting each directly onto the ordination and, where appropriate, by calculating vectors of maximum correlation (R_{max}) using the vector-fitting procedure of DECODA. Monte-Carlo tests, using 1000 random permutations of the data, were used to estimate the significance of each vector correlation. For the purposes of vector correlations, topographic class was treated as a sequence from gully to slope to rocky spur, and aspect a sequence from north-west to north-east. Where appropriate, vectors were used to order sites and species into two way tables indicating species contributing to relevant trends.

Results

Acacia scrubs of the study area were dominated by Currawang *A. doratoxylon,* which formed small trees to 20 m on lower slopes, and became smaller (to 3 m) on upper slopes and rocky spurs. *A. silvestris* was occasional at Little River, and became dominant on the rockiest sites at Farm Creek. Other overstorey trees included patches of *E. albens,* emergent *Eucalyptus saxatilis* at Little River and mallee-form *Eucalyptus smithii* at Farm Creek, and occasional *Allocasuarina verticillata* at Farm Creek. On very rocky sites *P. trachyphylla* replaced *A. doratoxylon* as the dominant, though usually with scattered emergent acacias. The understorey of the *Acacia* scrubs was generally sparse beneath the intact canopy (e.g. Fig. 1a).

A total of 64 native plant species was recorded across the 20 plots (39 at Little River and 54 at Farm Creek), including seven grass, one sedge, 30 forb, 17 shrub and sub shrub, two vine and seven tree species. A high proportion (20%) of these species are classified as rare or vulnerable in Victoria (Department of Sustainability and Environment 2005). Only six exotic species were recorded, all of which were herbaceous. Native species richness per 10 x 10 m plot ranged from 3 to 22 species, and exotic richness from 0 to 4. Total (cumulative) native cover was highly variable (range 6-71%), while exotic species cover was consistently very low (<2%). Understorey composition ranged from grass to shrub dominated and was generally different from surrounding grassy woodlands and dry forests.

Unburnt plots had a dense litter layer of *Acacia* phyllodes and twigs, with small amounts of bare soil and variable amounts of outcropping rock. Lightly burnt plots had approximately half the litter cover of unburnt plots (comprising litter accumulated since the fire and/or incomplete combustion of the pre-fire litter layer), and significantly more bare soil. On intensely burnt plots, the litter layer was largely removed by the fire and had not been replaced owing to canopy death. Bare soil levels of intensely burnt plots were similar to lightly burnt plots (Table 1).

Understorey cover at two years post-fire was significantly and dramatically influenced by fire intensity. Unburnt and lightly burnt plots generally had a sparse understorey of scattered shrubs and grass tussocks, with the exception of one unburnt plot located on a rocky spur and with a very dense cover (70%) of the shrub *Philotheca trachyphylla* (Fig 1a and b). Understorey cover increased to an average of 35% on intensely burnt plots (Fig. 1c), an increase of over 400% (excluding the anomalous *P. trachyphylla* plot, Table 1). Increases in cover due to intense burns were significant for the native shrub, grass and forb components of the understorey, but there were no significant effects on weed cover. Native shrub richness also increased on intensely burnt plots (Table 1).

Despite considerable variation in understorey composition between differing sets or pairs of plots, fire intensity correlated significantly with the nMDS ordinations (Figs. 2a, b; Table 2). On the presence-absence ordination, the correlation was relatively weak (R_{max}= 0.65). Unburnt plots were usually separated from burnt plots, but lightly burnt and intensely burnt plots were poorly distinguished from each other (Fig. 2a). On the quantitative ordination,

Fig. 1. Typical range in understorey density in Acacia scrubs at Little River in relation to burning intensity a) unburnt, b) lightly burnt, c) intensely burnt

Table 1. Adjusted means for understorey and ground cover characteristics of *Acacia doratoxylon* scrub two years after burning at different fire intensities. Means with different superscripts are significantly different from each other (P<0.05).

	Unburnt	Lightly Burnt	Intensely Burnt	P
Bare soil	6·0[a]	27·9[b]	24·1[b]	0.01
Exposed rock	36·0[a]	37·9[a]	26·6[a]	ns
Litter	49·3[a]	27·4[b]	7·6[c]	<0.001
Native richness	11·4[a]	12·5[a]	15·34[a]	ns
Native cover (%)	25·4[a]	8·3[b]	35·5[a]	0.021
Native cover (%) excl. *Philotheca*	8·1[a]	7·7[a]	34·7[b]	<0.001
Shrub richness	2·2[a]	3·3[a]	4·9[b]	0.006
Shrub cover (%)	21·8[a]	1·4[a]	18·6[a]	ns
Shrub cover (%) excl. *Philotheca*	4·5[a]	0·9[a]	17·9[b]	0.003
Grass richness	1·8[a]	1·4[a]	1·6[a]	ns
Grass cover (%)	-0·1[a]*	2·0[a]	10·1[b]	0.002
Forb richness	7·0[a]	7·9[a]	9·9[a]	ns
Forb cover (%)	3·6[a]	4·9[a]	7·3[b]	0.006
Weed richness	0·4[a]	0·6[a]	1·4[a]	ns
Weed cover (%)	0·2[a]	0·3[a]	0·7[a]	ns

*negative value due to adjustment; actual mean 1·9

Table 2. Vector correlations (R_{max}) of plot characteristics with ordinations using presence-absence and abundance data. P indicates significance of correlations.

	Presence/Absence		Abundance	
Plot characteristics	Rmax	P	R_{max}	P
Fire intensity	0·65	0·031	0·87	0·000
Topography	0·74	0·002	0·69	0·019
Site	0·62	0·064	0·66	0·021
Aspect	0·23	0·823	0·15	0·930

(a)

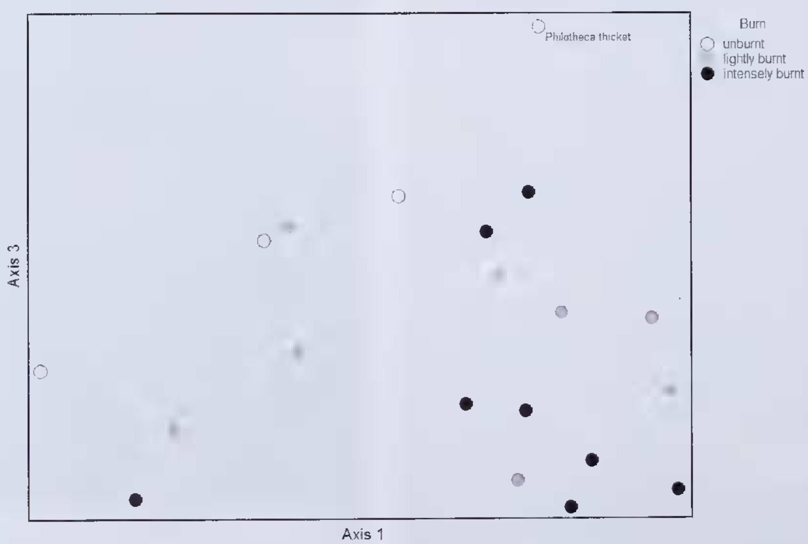
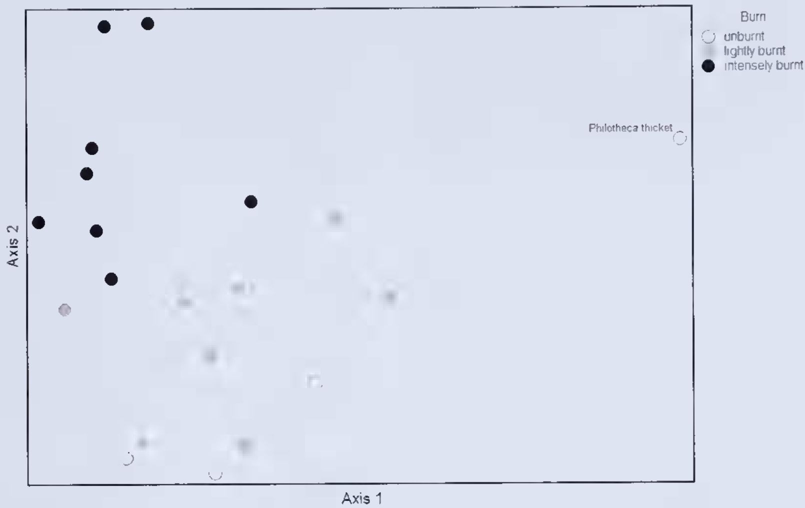


Fig. 2. nMDS ordination results for (a) presence-absence data showing relationships with burning intensity. Axes showing most distinct differences are presented.

(b)



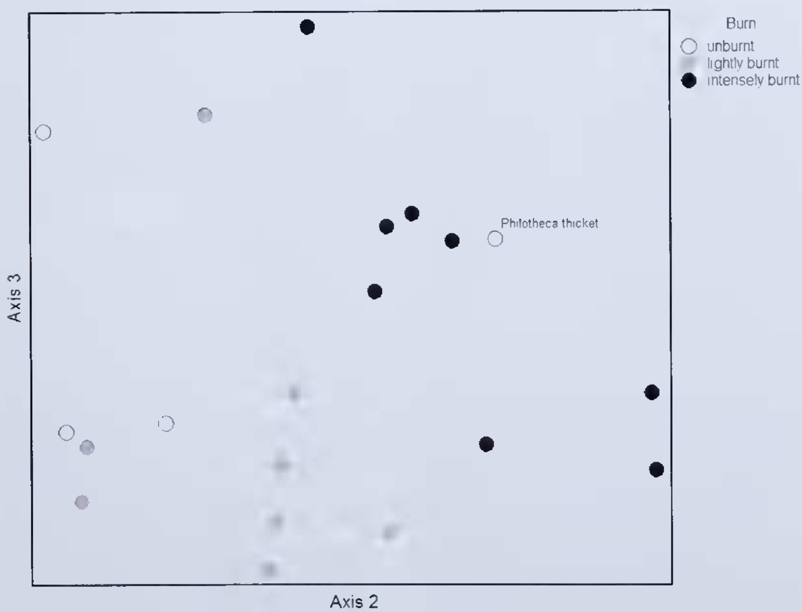


Fig. 2. cntd. nMDS ordination results for (b) abundance data (axes 1 versus axes 2 and axes 2 versus axes 3, showing relationships with burning intensity..

R_{max} increased to 0.87 and intensely burnt plots were distinctly separated from all others (Fig. 2b). This suggests that abundance of species played an important role in distinguishing lightly burnt from intensely burnt plots, consistent with analyses of cover estimates.

Differences in floristic composition related to fire intensity are indicated in Table 3. A number of species, such as *Platysace lanceolata, E. albens, Oxalis perennans, Galium liratum* and *Dichondra repens* showed no detectable relationship. Few understorey species were clearly more prominent in unburnt or lightly burnt plots, but it is possible that *P. trachyphylla* and *Dianella revoluta* were disadvantaged by intense fires. As well, the overstorey species *Allocasuarina verticillata* and *A. doratoxylon* were less frequent or abundant in intensely burnt plots owing to canopy death, consistent with our sampling strategy.

A distinct suite of species were absent from the understorey of unburnt plots, sparse or sporadic in lightly burnt plots, and frequent or abundant in intensely burnt plots (Table 3). These included the shrubs *Dodonaea rhombifolia, Muehlenbeckia diclina, Cyphanthera albicans* (absent from Farm Creek), *Solanum linearifolium*, and the forbs *Nicotiana suaveolens* and *Sigesbeckia australiensis*. A number of other species occurred occasionally or infrequently in unburnt plots, but increased markedly in frequency or abundance with increasing fire intensity, e.g. *Notodanthonia longifolia, Einadia hastata, Solanum prinophyllum* and *Lepidium pseudotasmanicum*. *Cynoglossum australe* and *Senecio hispidulus* increased in burnt plots but with no clear effects of fire intensity.

Ordinations using either presence-absence or abundance data also correlated significantly with topography (Table 2), with all five samples from rocky spurs distinguished from other topographic classes (slopes and drainage lines). A range of species (e.g. *Goodenia macmillanii, Lepidosperma laterale, Nicotiana suaveolens, Arthropodium milleflorum, Dichondra repens, Cheilanthes sieberi* and *Sigesbeckia australiensis*) was absent from plots on rocky spurs, while *Isotoma axillaris, A. silvestris* and *Philotheca trachyphylla* were most frequent in plots on rocky spurs (Table 4). There was little effect of aspect within these topographic classes, probably reflecting the limited range of aspects occupied by *Acacia* scrubs (NE to NW, Table 2).

There was also some distinction in understorey composition between the two sites (significant on quantitative ordination only, Table 2). This separation could be attributed to the absence from the Little River plots of species such as *Gonocarpus elatus* (present at Little River, but not in the plots), *Cheilanthes sieberi* and *Ozothamnus thyrsoideus*, and absence from the Farm Creek plots of *Cynoglossum australe, Parietaria debilis* and *Cyphanthera albicans*, as well as a greater frequency of species such as *Dodonea rhombifolia, Senecio hispidulus* and *Nicotiana suaveolens* at Little River.

Discussion

Acacia doratoxylon has not previously been described as dominant in *Acacia* scrubs in Victoria, but *A. doratoxylon* scrubs are noted from the adjoining Byadbo wilderness of NSW (Keith 2004). Clayton-Greene and Wimbush (1988) sampled a range of *Acacia* scrubs in the Upper Snowy region, and found *A. silvestris* was dominant in nine of 11 stands. However, they did not sample scrubs on rhyodacites owing to poor accessibility. Further surveys to elucidate the extent, status and environmental determinants of *A. doratoxylon* scrubs in Victoria would thus be of value.

The structure and floristic composition of *A. doratoxylon* compared with other *Acacia* scrubs is also of interest. In our study area, *A. doratoxylon* formed low forests to tall shrublands with open understorey, but did not form dense, impenetrable thickets as commonly reported for *A. silvestris* scrubs (Clayton-Greene and Wimbush 1988). A high proportion of the component plant species recorded in this study are listed as rare or vulnerable in Victoria (Department of Sustainability and Environment 2005), but it is not known whether these species are typical of other types of *Acacia* scrub. We also noted relatively sparse and slow-growing regeneration of *A. doratoxylon* (e.g. live cover values in intensely burnt plots were usually <1%, with seedlings mostly less than

Table 3. Two way table indicating the influence of fire intensity (U=unburnt, L=lightly burnt, I=intensely burnt) on understorey composition in 20 *Acacia* scrub samples at Little River Gorge and Farm Creek. Sites were ordered using the vector of maximum correlation for fire intensity for the quantitative nMDS ordination, and species were ordered according to their weighted average locations along this vector. Percent abundance is represented by the following classes: 1, <1%; 2, 1-2%; 3, 3-5%; 4, 6-10%; 5, 11-15%; 6, 16-25%; 7, 26-50%; 8, 51-75%; 9, 76-100%. All species that were recorded from 3 or more plots are included. Note that tree species (bold text) were not included in ordination analyses; low tree abundance on intensely burnt plots is due to canopy death.

Fire intensity	**L**	**U**	**U**	**L**	**U**	**L**	**U**	**L**	**L**	**L**	**L**	**L**	**I**	**I**	**I**	**I**	**I**	**I**	**I**	**I**
Philotheca trachyphylla	-	8	1	2	-	-	-	2	2	-	-	-	3	-	-	-	1	-	-	-
Allocasuarina verticillata	-	-	**3**	-	**1**	**1**	**1**	-	-	-	**2**	-	-	-	-	-	-	-	-	-
Acacia silvestris	-	**2**	**4**	**3**	-	-	-	-	**1**	-	-	-	**1**	-	**1**	-	-	**1**	**2**	**1**
Acacia doratoxylon	**8**	**6**	**8**	**8**	**9**	**8**	**7**	**7**	**7**	**8**	**8**	**7**	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**1**
Dianella revoluta s.l.	-	-	1	-	1	1	-	-	-	1	1	-	-	-	-	-	-	-	-	-
Lepidosperma laterale	1	-	-	-	1	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-
Clematis microphylla	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-	-	-	-
Galium binifolium	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-	-	-	-
Gonocarpus elatus	-	-	1	-	1	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-
Austrostipa densiflora	-	-	-	-	2	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-
Ozothamnus thyrsoideus	-	-	-	-	-	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-
Calandrinia calyptrata	1	-	1	1	-	1	1	-	1	-	-	-	-	-	1	1	1	-	-	-
Platysace lanceolata	1	-	-	1	1	-	-	-	-	-	1	-	-	1	-	-	-	-	1	-
Eucalyptus albens	**4**	**4**	**3**	-	**3**	-	**6**	-	**3**	**2**	**2**	-	**6**	**2**	**3**	**2**	**5**	**1**	-	**2**
Pleurosorus rutifolius	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	1	-	-	-
Crassula sieberiana	1	-	-	1	-	-	-	1	-	1	-	-	-	-	-	1	-	-	1	-
Oxalis perennans	1	-	1	-	1	1	1	-	1	1	1	1	1	1	1	1	1	1	-	-
Arthropodium milleflorum	-	-	1	-	-	1	1	-	-	-	-	-	-	-	1	1	1	-	-	-
Galium liratum	1	-	1	-	-	-	-	1	1	1	-	-	1	-	1	-	-	1	-	1
Isotoma axillaris	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1
Dichondra repens	1	-	1	-	-	1	1	-	-	1	-	-	-	-	1	2	1	1	-	-
Cheilanthes sieberi	-	-	-	-	1	1	1	-	-	-	1	-	-	2	1	-	-	-	-	-
Lepidium pseudotasmanicum	-	-	-	-	-	1	1	1	1	-	-	1	1	-	1	1	1	1	-	-
Solanum prinophyllum	-	-	1	-	-	-	-	1	-	-	-	-	1	1	-	1	1	-	-	-
Einadia hastata	1	1	1	1	-	2	2	-	2	2	-	3	4	-	2	2	3	2	1	1
Sonchus oleraceus	-	-	1	-	-	1	-	-	1	1	-	-	-	-	1	1	-	-	1	1
Sonchus asper	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	1
Senecio hispidulus	-	-	-	-	-	1	-	1	1	1	-	1	-	-	-	1	-	1	1	2
Solanum linearifolium	-	-	-	-	-	-	-	1	-	-	-	-	2	2	1	2	1	1	-	-
Notodanthonia longifolia	1	1	1	1	2	1	1	1	2	2	3	1	4	6	4	2	5	5	2	3
Cynoglossum australe	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	2	-	1	-	1
Nicotiana suaveolens	-	-	-	-	-	-	-	-	-	2	-	2	-	-	3	3	2	1	-	1
Parietaria debilis	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	1	-
Goodenia macmillanii	1	-	-	-	-	1	1	-	-	-	-	2	-	-	-	1	5	-	-	-
Sigesbeckia australiensis	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	2	1	-	-	1
Cyphanthera albicans	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-	3	2	2
Muehlenbeckia diclina	-	-	-	1	-	-	-	1	1	1	1	-	2	1	3	4	3	4	3	5
Dodonaea rhombifolia	-	-	-	-	-	-	-	1	1	-	-	1	-	-	2	4	-	2	6	6
Eucalyptus saxatilis	**1**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**3**	**3**

0·5 m), compared with dense and robust regeneration in nearby *A. silvestris* scrubs (post-fire live cover to 50%, with many seedlings to 2 m in height, pers. obs.).

Effects of fire on vegetation structure and floristics

Consistent with earlier reports, the understorey of the *Acacia* scrubs of this study was sparse beneath the intact canopy (e.g. Fig. 1a), or dominated by dense *Philotheca trachyphylla* in rocky situations (Forbes *et al.* 1982, Clayton-Greene and Wimbush 1988, Keith and Bedward 1999). Richness ranged from 3-19 species (average 12) in unburnt plots; higher than reported by Keith (2004) for *Acacia* scrubs in NSW.

Surveys indicated that light burns led to minimal change in total understorey abundance, and sporadic establishment of a range of species that were rare or absent in the understoreys of unburnt sites. By contrast, burns that were intense enough to kill the *Acacia* overstorey stimulated dense

Table 4. Two way table indicating the influence of topography (G=gully, S=slope, R=rocky spur) on understorey composition in 20 *Acacia* scrub samples at Little River Gorge and Farm Creek. Sites were ordered using the vector of maximum correlation for topography for the quantitative nMDS ordination, and species were ordered according to their weighted average locations along this vector. Percent abundance is represented by the following classes: 1, <1%; 2, 1-2%; 3, 3-5%; 4, 6-10%; 5, 11-15%; 6, 16-25%; 7, 26-50%; 8, 51-75%; 9, 76-100%. All species that were recorded from 3 or more plots are included.

Topography	**G**	**S**	**S**	**S**	**S**	**G**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**R**	**S**	**R**	**R**	**R**	**R**
Pleurosorus rutifolius	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Goodenia macmillanii	2	1	1	5	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Ozothamnus thyrsoideus	-	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Clematis microphylla	-	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Galium binifolium	-	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidosperma laterale	-	1	1	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-
Nicotiana suaveolens	2	-	-	2	3	3	-	1	2	-	-	-	1	-	-	-	-	-	-	-
Arthropodium milleflorum	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Dichondra repens	-	1	1	1	1	2	1	1	1	-	-	-	-	-	-	1	-	-	-	-
Cheilanthes sieberi	-	1	1	-	1	-	-	-	-	2	1	1	-	-	-	-	-	-	-	-
Cynoglossum australe	1	-	-	-	-	2	-	1	1	-	-	-	1	-	-	-	-	-	-	-
Sigesbeckia australiensis	-	-	-	1	1	2	-	-	1	-	-	-	1	-	-	-	-	-	-	-
Oxalis perennans	1	1	1	1	1	1	1	1	1	1	1	1	-	1	-	1	1	-	-	-
Lepidium pseudotasmanicum	1	1	1	1	1	1	-	1	-	-	-	-	-	1	-	-	1	1	-	-
Sonchus asper	1	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
Calandrinia calyptrata	-	1	1	1	1	1	1	-	-	-	-	-	-	1	-	1	-	-	1	-
Notodanthonia longifolia	1	1	1	5	4	2	1	5	2	6	2	3	3	2	2	1	4	1	1	1
Einadia hastata	3	2	2	3	2	2	1	2	2	-	-	-	1	2	1	1	4	-	1	1
Dianella revoluta	-	-	1	-	-	-	-	-	1	-	1	1	-	-	-	1	-	-	-	-
Austrostipa densiflora	-	-	-	-	-	-	-	-	-	1	2	1	-	-	-	-	-	-	-	-
Parietaria debilis	-	-	-	-	-	1	-	1	1	-	-	-	-	-	1	-	-	-	-	-
Senecio hispidulus	1	-	1	-	-	1	-	1	1	-	-	-	2	1	1	-	-	1	-	-
Sonchus oleraceus	-	-	1	-	1	1	-	-	1	-	-	-	1	1	1	1	-	-	-	-
Muehlenbeckia diclina	-	-	-	3	3	4	-	4	1	1	-	1	5	1	3	-	2	1	1	-
Gonocarpus elatus	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	1	-	-	-	-
Acacia doratoxylon	**7**	**7**	**8**	**2**	**1**	**1**	**8**	**1**	**8**	**1**	**9**	**8**	**1**	**7**	**1**	**8**	**1**	**7**	**8**	**6**
Solanum linearifolium	-	-	-	1	1	2	-	1	-	2	-	-	-	-	-	-	2	1	-	-
Cyphanthera albicans	-	-	-	-	-	1	-	3	1	-	-	-	2	-	2	-	-	-	1	-
Allocasuarina verticillata	**-**	**1**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**2**	**-**	**-**	**-**	**3**	**-**	**-**	**-**	**-**
Eucalyptus albens	**-**	**6**	**-**	**5**	**3**	**2**	**4**	**1**	**2**	**2**	**3**	**2**	**2**	**3**	**-**	**3**	**6**	**-**	**-**	**4**
Dodonaea rhombifolia	1	-	-	-	2	4	-	2	-	-	-	-	6	1	6	-	-	1	-	-
Platysace lanceolata	-	-	-	-	-	-	1	-	-	1	1	1	-	-	1	-	-	-	1	-
Solanum prinophyllum	-	-	-	1	-	1	-	-	-	1	-	-	-	-	-	1	1	1	-	-
Galium liratum	-	-	-	-	1	-	1	1	1	-	-	-	1	1	-	1	1	1	-	-
Eucalyptus saxatilis	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**3**	**-**	**3**	**-**	**-**	**-**	**-**	**-**
Crassula sieberiana	-	-	-	-	-	1	1	-	1	-	-	-	-	-	1	-	-	1	1	-
Isotoma axillaris	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	1	1	-
Acacia silvestris	-	-	-	-	1	-	-	1	-	-	-	-	1	1	2	4	1	-	3	2
Philotheca trachyphylla	-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	1	3	2	2	8

establishment and robust growth of species absent from understoreys of unburnt plots, leading to a significant increase in native shrub richness and understorey abundance. As well, intense burns promoted lush growth of the grass *Notodanthonia longifolia* and forbs such as *Einadia hastata*.

Processes leading to these understorey changes are likely to involve both direct effects of fire on seed dormancy and germination, and release from intense competition for light, soil moisture and/or soil nutrients after overstorey death. As well, a flush of soil nutrients may have occurred with the breakdown of root systems of dead *Acacias* (Fisher and Binkley 2000).

The importance of the overstorey for suppressing understorey species is further evident from field observations, where sharp boundaries between dense and sparse understorey are coincident with boundaries between killed and live canopy respectively (e.g. Fig. 3).

Infrequent, intense fires have previously been recognized as important for stimulating recruitment of overstorey species and thus the perpetuation of *Acacia* scrubs in far south-eastern Australia (Clayton-Greene and Wimbush 1988). This study indicated that a range of understorey species are also dependent on intense fires in these communities, where they occur mostly as post-fire ephemerals (*sensu* Gill 1993, becoming abundant only after intense fires, and existing as scattered individuals and/or a dormant seed bank for long periods). Many of these species in Little River Gorge are vulnerable, rare or disjunct in Victoria (Table 5), and thus the appropriate fire management of *Acacia* scrubs is of significant conservation interest.

While the dramatic effects of canopy burns on understorey composition and vigour were readily evident in the field, a caveat must be placed on conclusions of this study. Because monitoring plots were established after the fire, some confounding of understorey composition with fire intensity may have occurred due to the influence of pre-fire vegetation on fire behaviour. For example, observations before the fire (R Martin, pers. comm.) suggest that some areas had high cover of dry grass thatch, and these may have been more flammable than other areas. Consequently, it is possible that pre-fire vegetation in intensely burnt areas was naturally somewhat denser than in unburnt areas. Nevertheless, observations of the vegetation before the fire (R Martin, pers. comm.) confirm that many species that flourished after the fire (e.g. *Cyphanthera albicans, Muehlenbeckia diclina, Dodonaea rhombifolia*) were uncommon to very rare in the understorey before the fire, and that other species were common but less robust and abundant than after the fire (e.g. *Goodenia macmillanii*).

Implications for fire management

Some preliminary conclusions regarding appropriate fire regimes for managing *Acacia* scrubs and *Petrogale penicillata* habitat in Little River Gorge might be drawn based on conditions at two years post-fire. In particular, the strong differentiation of intensely-burnt plots from unburnt and lightly-burnt plots suggests that only intense, canopy-killing fires are suitable for releasing many fire-recruiting species from the seedbank, and for promoting vigorous understorey growth in *A. doratoxylon* scrubs. By contrast, controlled, low-intensity fires as usually applied in management burns may not be sufficient to kill the canopy and hence promote significant recruitment and growth of understorey species.

Fig. 3. Sharp boundaries in understorey abundance relating to canopy death were typical across burnt areas at Little River and Farm Creek. All of the area in this image was burnt during the 2003 fire. However, canopy on the left was killed, corresponding with lush understorey growth, while canopy on the right was largely intact and understorey remains sparse.

Table 5. Fire responses of rare, vulnerable or disjunct species at Little River and/or Farm Creek.

Species	Distribution in Victoria (Walsh and Entwisle 1994-1999)	DSE[#] (2005) classification	Notes (including fire response observed)
Acacia doratoxylon Currawang	Common and widespread in semi-arid NSW, disjunct outlier in eastern Victoria	Rare	Killed by intense fire, which stimulates germination of new generation
Cyphanthera albicans subsp. *albicans* Hoary Rayflower	Rare in Victoria where known only from a few localities in the upper Snowy River area	Rare	Post-fire ephemeral*
Dodonaea rhombifolia Broad-leaf Hop-Bush	Disjunct in eastern Victoria viz. Pine Mountain and Snowy and Combienbar River	Rare	Post-fire ephemeral*
Eucalyptus saxatilis Suggan Buggan Mallee	Known from few localities, viz. Stradbroke Chasm, Mt Wheeler and Little River Gorge.	Vulnerable	No seedlings seen. Vigorous post-fire resprouting, but frequent tree and/or resprout death due to post-fire drought.
Goodenia macmillanii Pinnate Goodenia	Rare endemic in Victoria, known only from rocky slopes in rainshadowed valleys of the Macalister, Snowy and Deddick Rivers.	Vulnerable	Enhanced by fire
Haloragodendron baeuerlenii Shrubby Raspwort	In Victoria confined to far east between Suggan Buggan, Mt Tingaringy and Snowy River Gorge, on rocky spurs.	Rare	Not seen during this study but previously recorded from Little River *Acacia* scrubs
Muehlenbeckia diclina subsp. I Twiggy Lignum	Known only from upper Snowy River area and near Licola.	Rare	Post-fire ephemeral*
Nicotiana suaveolens Austral Tobacco	Widespread in drier inland, with disjunct occurrences in Snowy River and East Gippsland areas.	Rare	Post-fire ephemeral*
Pomaderris eriocephala Woolly-head Pomaderris	Endemic in Victoria, scattered on shallow rocky soils east from near Bairnsdale.	Rare	Recorded in only 2 plots (lightly and intensely burnt)
Scleranthus diander Tufted Knawel	Mostly in stony soils of montane grassland and open woodlands above 500m.	Rare	Recorded in only 2 plots (unburnt and lightly burnt)
Senna aciphylla Sprawling Cassia	In Victoria confined to the east, usually on rocky slopes in woodland scrubs.	Rare	Recorded in only 1 plot (unburnt)
Solanum linearifolium Mountain Kangaroo-apple	In Victoria, apparently restricted to montane forests between Omeo and Mt Tingaringy, often appearing following disturbance or bushfire.	Rare	Post-fire ephemeral*
Teucrium thieleanum.	New species of *Teucrium* found at Farm Creek and Little River. (see Conn 2006)	Unknown	Occasional occurrences in burnt areas, flourishing after the fire. Not recorded in permanent plots.

[#]Department of Sustainability and Environment

*i.e. abundance in understorey in relation to fire: rare in unburnt plots, sporadic in lightly burnt plots, frequent or abundant in intensely burnt plots; longevity unknown

While intense fires are likely to be critical for conservation of *Acacia* scrubs, ecologically appropriate fire return times are probably relatively high. Appropriate fire frequencies for maintaining plant species diversity and natural processes in the *A. doratoxylon* communities will involve a balance between a sufficient fire-free period for successful maturation of *Acacia* stands, and rare, hot (canopy-killing) fires to promote post-fire ephemerals and replenish their seed banks before soil seed stores senesce. A greater understanding of the longevity of such seed stores, and of the *Acacia* overstorey, is needed to indicate the optimal frequency of intense fires.

Further studies are needed to evaluate the net benefit or disadvantage of intense fires for *P. penicillata.* An initial disadvantage might be expected during the immediate burn and post-burn period, but in the medium-term the wider richness and abundance of plant species present could provide better feed and cover for foraging animals. It is likely that fire return times appropriate for maintaining *Acacia* scrubs would be too long for intense burns to provide a practical management option for enhancing feed and cover availability over the long term. Thus if availability of feed and/or cover is shown to be an important limit to *P. penicillata* populations, alternative options would need to be considered, including suppression of the *Acacia* overstorey in small patches or augmentation of feed and cover through other means.

Acknowledgements

This study was initiated and supported by the Department of Sustainability and Environment, Victoria. We thank Lucy Clausen for assistance with field work and Raz Martin for information on conditions before and during the fires. Terry Koen (NSW Department of Natural Resources) provided statistical advice.

Note

[1] Nomenclature follows Wheeler *et al.* (2002) for grasses and Walsh and Entwisle (1994-1999) for other species.

References

Clayton-Greene KA and Wimbush DJ (1988) *Acacia* dry scrub communities in the Byadbo area of the Snowy Mountains. *Cunninghamia* **2**, 9-24.

Conn BJ (2006) *Teucrium thieleanum* (Labiatae), a new species from Victoria, Australia. *Telopea* **11**, 135-40.

Costin AB (1954) *A Study of the Ecosystems of the Monaro Region of New South Wales with Special Reference to Soil Erosion.* (Soil Conservation Service of NSW: NSW)

Department of Sustainability and Environment (2005) *Advisory list of rare or threatened plants in Victoria.* (Victorian Department of Sustainability and Environment: East Melbourne, Victoria)

Faith DP, Minchin PR and Belbin L (1987) Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69, 57-68.

Fisher RF and Binkley D (2000) *Ecology and Management of Forest Soils.* 3 ed (John Wiley and Sons: New York)

Forbes SJ, Walsh NG and Gullan PK (1982) Vegetation of East Gippsland. *Muelleria* **5**, 53-114.

GenStat (2003) *GenStat Release 7.1 Guide to GenStat Part 2: Statistics.* (VSN International Limited: Oxford, UK)

Gill AM (1993) Interplay of Victoria's flora with fire. In *Flora of Victoria. Volume I Introduction*, pp. 212-226. Eds DB Foreman and NG Walsh. (Inkata Press: Melbourne)

Keith DA (2004) *Ocean Shores to Desert Dunes. The native vegetation of New South Wales and the ACT.* (Department of Environment and Conservation: NSW)

Keith DA and Bedward M (1999) Native vegetation of the South East Forests region, Eden, New South Wales. *Cunninghamia* **6**, 1-60.

McCune B and Mefford MJ (1999) *PC-ORD. Multivariate analysis of ecological data.* Version 4. (MjM Software Design: Oregon)

Minchin PR (1989) *DECODA user's manual.* (Australian National University: Canberra)

Steel RGD and Torrie JH (1981) *Principles and Procedures of Statistics. A Biometrical Approach.* 2 ed (McGraw-Hill: London)

Walsh NG and Entwisle TJ (1994-1999) (eds.) *Flora of Victoria*, Vols 2-4. (Inkata Press: Melbourne)

Wheeler DJB, Jacobs SWL and Whalley RDB (2002) *Grasses of New South Wales*, 3 ed (University of New England: Armidale)

Woodgate PW, Peel WD, Ritman KT, Coram JE, Brady A, Rule AJ and Banks JCG (1994) *A Study of the Old Growth Forests of East Gippsland.* (Department of Conservation and Natural Resources: Victoria)

Received 18 May 2006; accepted 12 July 2007